A Study of the Berea Sandstone and Hydrocarbon Entrapment Within it in Belmont and Monroe Counties, Ohio

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by

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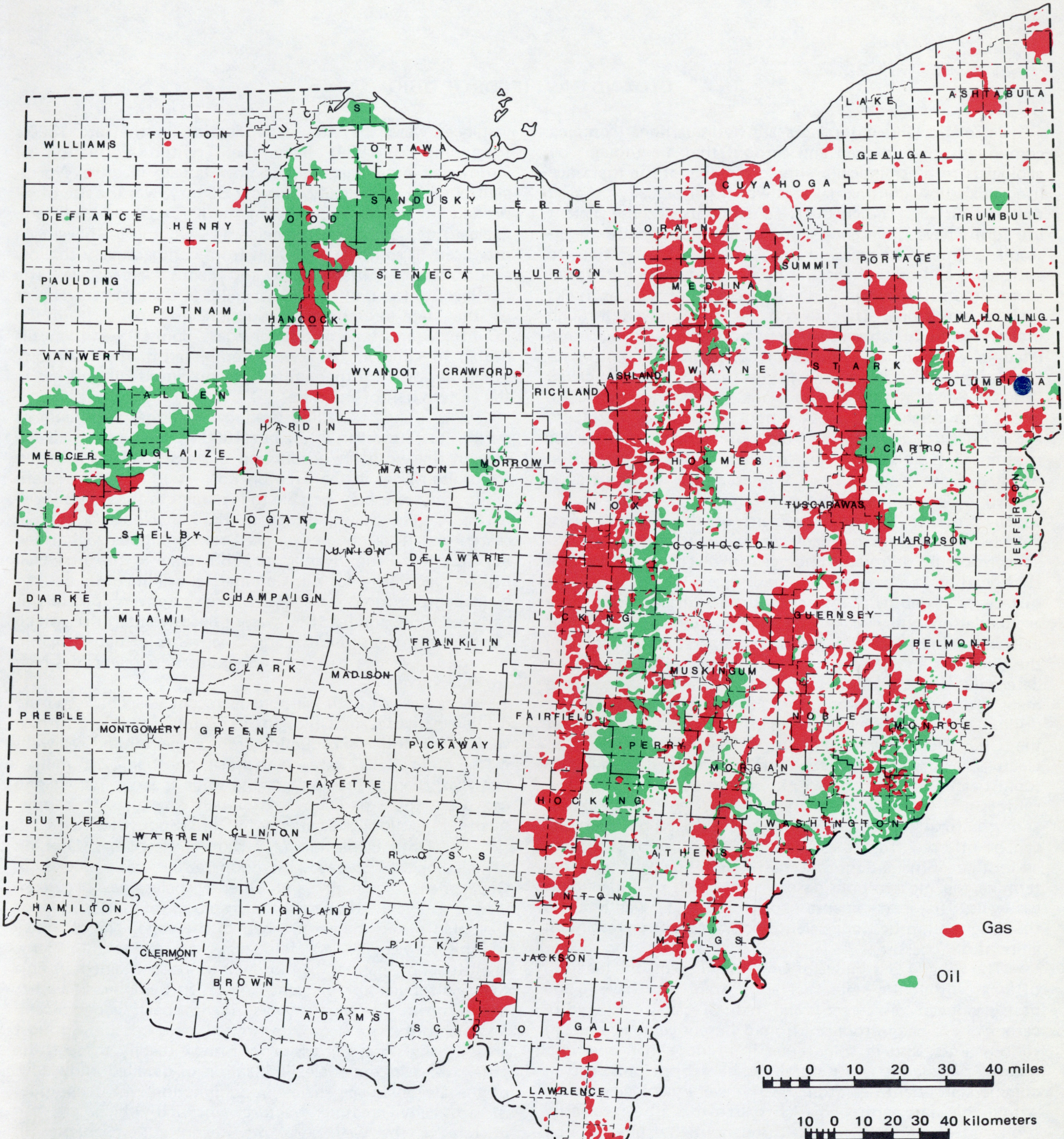

STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY

OIL AND GAS FIELDS OF OHIO

Areas in which oil or gas is being produced or has been produced commercially since 1860.

A detailed version of this map, at a scale of 1 inch = about 8 miles, also is available. This more detailed map provides data on discovery date, depth, and producing horizon of individual pools, and stratigraphy. Natural gas and liquid petroleum storage areas in Ohio also are shown.

OIL AND GAS FIELDS OF OHIO

Petroleum and natural gas are hydrocarbons (complex compounds of hydrogen and carbon) that are thought by geologists to be chemically altered remains of life that once lived in shallow continental seas which periodically covered the land surface. The chemical constituents of these ancient life forms have undergone complex and imperfectly understood chemical changes in the process of alteration to petroleum and natural gas and have accumulated in the tiny spaces (pores) between individual grains of porous rocks such as sandstone. The oil and gas later moved through interconnections between adjacent pore spaces and accumulated in economically important concentrations known as "pools." Pools accumulate in geologic structures called "traps." Pools of hydrocarbons are not underground lakes, as the term might imply, but simply areas where petroleum and/or natural gas saturate the pore spaces in a porous stratum of rock, termed the "reservoir." The accumulation of oil and gas is aided when the reservoir rock in a trap is capped by an impermeable layer of rock, or "cap rock," which prevents further movement of the hydrocarbons. Petroleum traps are of many varieties and are a principal concern of the petroleum geologist involved in exploration. Hydrocarbon accumulations may occur at or near the surface or at depths of several thousands of feet. Subsurface accumulations may give no surface indication of their existence. The petroleum geologist prepares maps depicting the thickness and structure of various rock strata in order to determine the possible presence of hydrocarbon traps. These maps are prepared from information recorded during the drilling of oil and gas wells. These records are kept on file at the Ohio Department of Natural Resources, Division of Geological Survey. Additional data are obtained from highly sophisticated research devices known as borehole geophysical logs and from surface geophysical surveys. The thickness and structural attitude of potential hydrocarbon reservoirs can be inferred from these data. Through use of such data and other information, the petroleum geologist can determine the most promising areas in which to drill oil and gas wells. The great expense of each individual well requires that exploration be done scientifically and with a minimum amount of "guessing."

The Oil and Gas Fields of Ohio map depicts the location of areas within the state that are currently or have in the past produced oil (green) and natural gas (red). Hydrocarbons have been produced from different geologic units in various areas, and in some areas from more than one unit; indeed, petroleum and natural gas have been produced in commercial quantities from nearly every geologic system within the state, although each system has not necessarily produced oil and natural gas throughout the state. The oil and gas fields in the northwestern portion of the state, for instance, were the site of production in the late 1800's (beginning in 1884) from the Trenton Formation of Ordovician age. This field is now largely inactive. North-central Ohio, principally Morrow County, was the site of oil production in the 1960's from the Knox Dolomite (Trempealeau) of Cambrian-Ordovician age. Oil and gas have been produced in southeastern Ohio from comparatively shallow sandstones of Mississippian and Pennsylvanian age. The north-south trend of oil and gas fields in the east-central part of the state represents production principally from the "Clinton" sandstone of Silurian age. About 80% of the wells drilled in Ohio in 1977 were completed in the "Clinton" sandstone. Many other units have produced oil and gas in the eastern half of the state.

Ohio is not a leading producer of either petroleum or natural gas; however, in the late 1800's Ohio was the leading area in the world in production of these fuels, principally from discoveries in the Trenton Formation in northwestern Ohio. The state may be able to lay claim to the first oil well in the United States, drilled in 1814 in Noble County in search of salt, although Colonel Drake's famous well drilled at Titusville, Pennsylvania, in 1859 ranks as the first well drilled specifically for oil. Commercial drilling of oil and gas wells began in Ohio soon after Drake's discovery, possibly as early as 1859, and by 1860 was a full-scale enterprise, which continues to the present. Large discoveries of natural gas in the state gave rise to numerous industries, many of which are still active.

Shortages of hydrocarbons in recent years have spurred drilling activities in Ohio; in 1977 more than 2,500 new wells were drilled. Production from active oil and gas wells in the state in 1977 was valued at more than $275 million per year; slightly over half of the value is from gas. Oil and gas production in Ohio is of much assistance in supplementing the supplies of energy to Ohio's industries.

The Ohio Department of Natural Resources, Division of Geological Survey, in cooperation with the U.S. Department of Energy and other agencies, has begun an intensive examination of the geology of the shales of Devonian age in the eastern half of the state. The objective of this project is to find ways to extract the large quantities of natural gas known to be contained in this shale. Although the existence of gas in the Ohio Shale has been known for many years, it has been economically feasible to extract it only in limited areas because, in most areas of the state, the gas cannot move readily through the pore spaces in the shale. Utilization of detailed knowledge of the Devonian-age shales, in conjunction with techniques of artifically creating fractures through which gas can migrate to the well bore, may open a new chapter in production of natural gas in Ohio.

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ILLUSTRATIONS

INTRODUCTION

Ohio has long been an active producer of oil and natural gas. Since the late 1800's, there has been almost continual drilling and producing activity. The drastic increase in the world price of oil in 1973, coupled with increased production of the "Clinton" Sands (Silurian), has made Ohio the fifth largest oil producing state in the USA (and fifth to some rather formidable contenders the likes of Texas, Oklahoma, Louisiana and Kansas) (AAPG Bulletin, October, 1981).

About 73% of the new wells drilled here in 1980 were "Clinton" wells (AAPG Bulletin, October, 1981). However, most of the remaining wells were drilled to a lesser known, but prolific, lower Mississippian formation -- the Berea Sand. Berea oil exploitation has taken place mainly in the southeastern part of the state. Being much shallower than the "Clinton", the Berea was one of the first oil sands to be explored in Ohio. Thousands of wells have been produced since the turn of the century, and many of the old Berea fields once thought to be "played out" are now being given a closer look by oilmen.

Belmont and Monroe Counties, Ohio were once areas of active Berea production. They are located along the Ohio River between the cities of Steubenville and Marietta (Figure 2). Although this area was never a leading producer, it has had steady production since the 1890's. The period

Fig. 2 Map showing location of study area and extent of subsurface Berea Sandstone.

of most active drilling was between 1890 and 1930 (Berryhill, 1963). New wells are drilled here each year with moderate success.

Even though this area has been explored, it is the belief of the author that there are remaining commercial quantities of oil and gas in the Berea and other formations. Most of the known gas and oil pools were produced more than fifty years ago with crude production techniques. Geologists with Ohio independent oil companies reported to the author as much as 90+% of the oil is left in the producing formation with old recovery techniques. Thus, even if few new pools are to be found, the older Berea fields are worthy of reworking. Modern "hydrofracing" techniques can boost recovery by several percent, and renew production on wells thought to have been exhausted.

While conducting this investigation at the Ohio Division of Geological Survey, the author met several geologists who were conducting studies on the same areas for Ohio independents. This is an indication that the Belmont-Monroe Counties area is still interesting to commercial oil producers and that activity will continue. The competition for oil and gas leases in Ohio has become fierce. There are no more "easy" claims, and independents must now use more scientific exploration techniques. (The old school was to drill wherever there was a lease or a pipeline.) Also, a report has been submitted to the Department of Energy by the State of

Ohio in order to gain "tight" sand designation for the Berea. Independents can receive increased prices for natural gas produced from "tight" formations. Tight sands is a DOE classification for a sand of a restricted thickness and reduced porosity from which production is more difficult and costlier.

PURPOSE OF STUDY

The aim of this thesis is to investigate oil and gas production in the Berea Sand, and to study the method of hydrocarbon entrapment within the Berea in parts of Belmont and Monroe Counties, Ohio. The author will characterize the conditions which have been favorable for oil and gas entrapment and make conjectures on areas and horizons other than Berea which may contain hydrocarbons.

The best method to accomplish this is by means of a subsurface study. Several geologists have conducted such studies prior to the present author, most notably Pepper, DeWitt, and Demarest. Their work was so exhaustive that it has remained unchallenged for almost thirty years.

The study conducted by Pepper et al. on the Berea Sandstone was done on a regional scale, encompassing parts of eastern Ohio, western Pennsylvania, eastern Kentucky and West Virginia. These authors produced a regional isopach map of the Berea, but without the benefit of Radioactivity Well Logs.

A portion of this appears in Figure 3. My subsurface study is conducted in a smaller area and utilizing as many Radioactivity Logs as are available. This newer well logging technique produces well data which is more accurate than the old driller's logs. It is the intention of this author to more precisely map the Berea Sand in the study area and investigate the hydrocarbon entrapment via the new data.

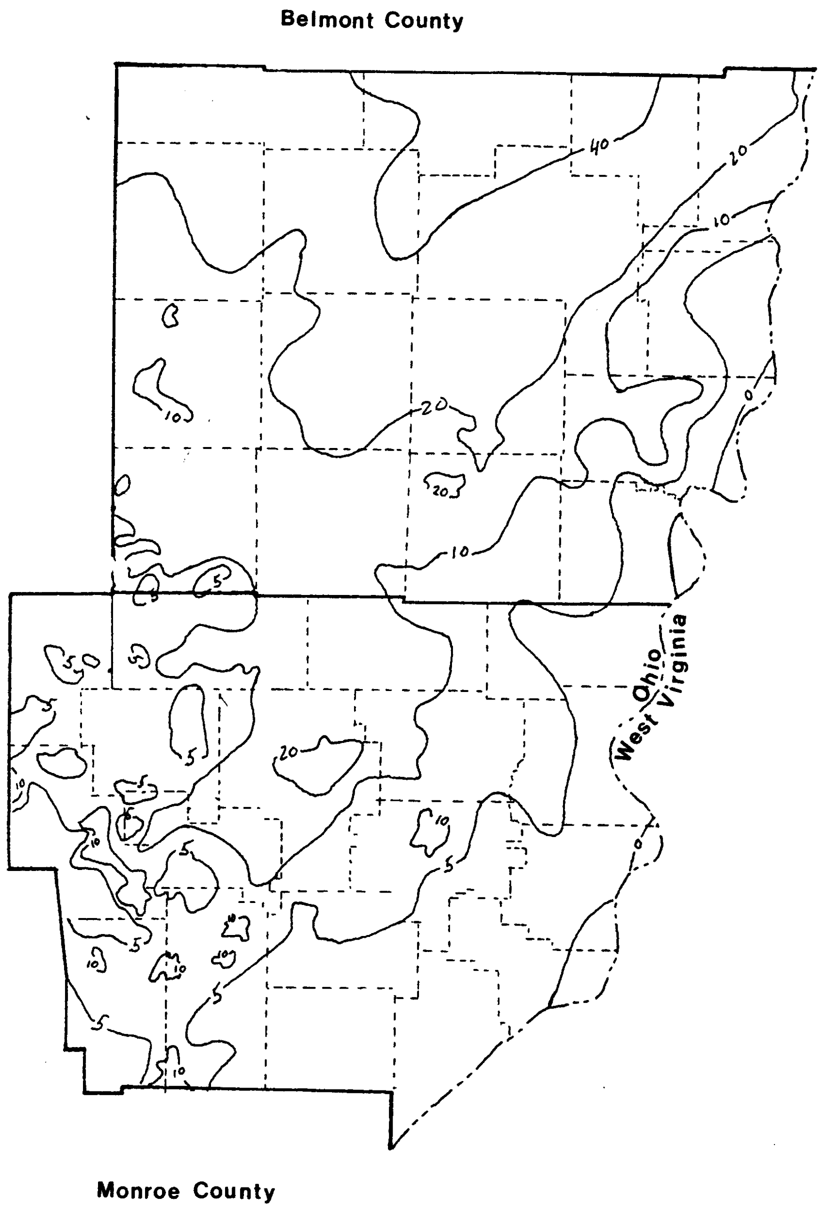


Fig. 3 A Portion of the Isopach Map of the Berea Sandstone by Pepper et al, 1954.
Contour Interval – five feet.

This study utilizes more than sixty gamma ray and neutron density logs as well as over seventy-five supplemental driller's logs. The aforementioned are on file at the Ohio Division of Geological Survey at Fountain Square, Columbus, Ohio. Also in the study from these files are core descriptions to characterize the lithology of Berea formation. The above data is combined to prepare a detailed isopach map of the Berea in the study area (see Plate I). A cross section is also included to illustrate changes in the "Sand" in the study area. Also, a structure-contour map of the Berea Sandstone recently prepared by John D. Gray of the Ohio Division of Geological Survey, is included (see Plate II). A general description of the Berea precedes the discussion of the hydrocarbon entrapment.

STRATIGRAPHY

The Berea Sandstone was first named and described by J.S. Newberry in 1870 after the great sandstone quarries at the type locality of Berea, Ohio. It is an early Mississippian formation in the Waverly Series. It is a persistant sand which occurs in much of eastern Ohio, western Pennsylvania, eastern Kentucky and West Virginia. It is described by Pepper et al. as a "medium to fine grained, gray, claybonded quartz sandstone". The Berea is bounded stratigraphically by shale; the Bedford below and the Sunbury above (Figure 4).

The Berea is recognized as having three phases (DeWitt, 1951). The first and oldest being the massive medium grained sandstone which fills channels scoured into the Bedford Shale. DeWitt (1951) reports the sandstone as "finely laminated, showing crossbedding, containing flattened pebbles and pyritic cement." Correlation of this phase to the stratigraphically similar Cussewago Sandstone by Prosser in 1912 was erroneous due to differences in petrography and deposition direction (DeWitt, 1951).

The second phase is a "sheet" sand about twenty-five feet thick throughout Ohio. It is a fluvitile sand containing crossbedding and stream scours deposited prior to inundation of the region by the sea.

The third phase is a stage of deposition occurring after a major transgression of the sea into Ohio. This sand is

ERA	PERIOD	SYSTEM	SERIES	FORMATION	MEMBER
PALEOZOIC	MISSISSIPPIAN	MISSISSIPPIAN		MAXVILLE LS	
				LOGAN FM	VINTON SS ALLENSVILLE CGL BYER SS BERNE CGL
				CUYAHOGA FM	BLACK HAND SS PORTSMOUTH SH BUENA VISTA SS HENLEY SH
				SUNBURY SH	
				BEREA SS	
				BEDFORD SH	CUSSEWAGO SS
	DEVONIAN	DEVONIAN	CHAUTAUQUAN	OHIO SHALE	CLEVELAND SH CHAGRIN SH HURON SH
			SENECAN		
				OLENTANGY SH	
			ULSTERIAN	DELAWARE LS	
				COLUMBUS LS	

Fig. 4 Stratigraphic Column of Devonian & Mississippian of Southeast Ohio.

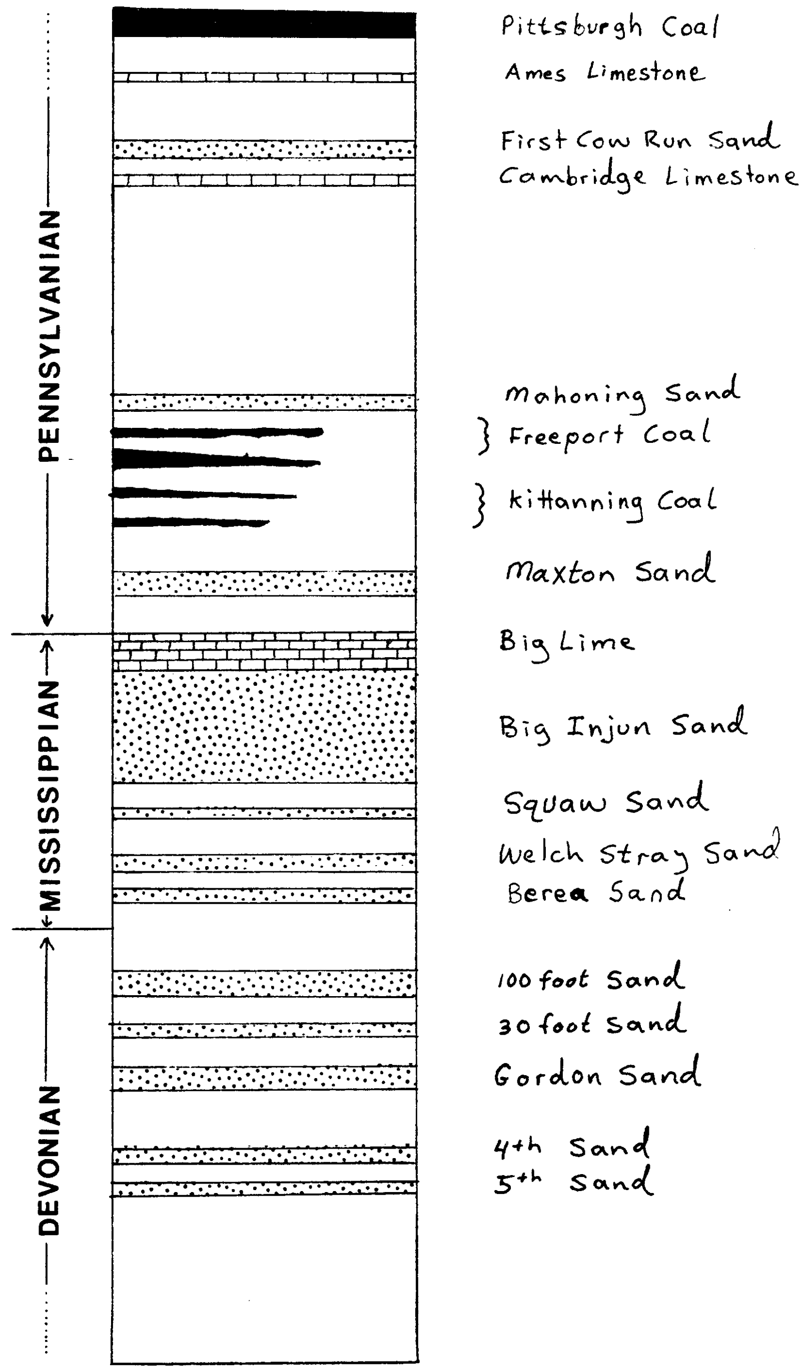


Fig. 5 Generalized section of pay sands (driller's names) in Belmont County, Ohio.

five to twenty-five feet thick containing abundant ripple marks resulting from currents and waves in the shallows of Ohio Bay.

The Berea Sandstone feathers out to the southeast (zero isopach thickness line approximately follows the Ohio River; see Plate I). The sediments in the study area are mostly siltstones and very fine grained sandstones spread along the eastern shore of the Bay. In the study area, the Berea ranges in thickness from zero to over thirty feet. It is primarily siltstone containing lenses of fine grained sandstone which we will later discuss as a reservoir for oil and gas.

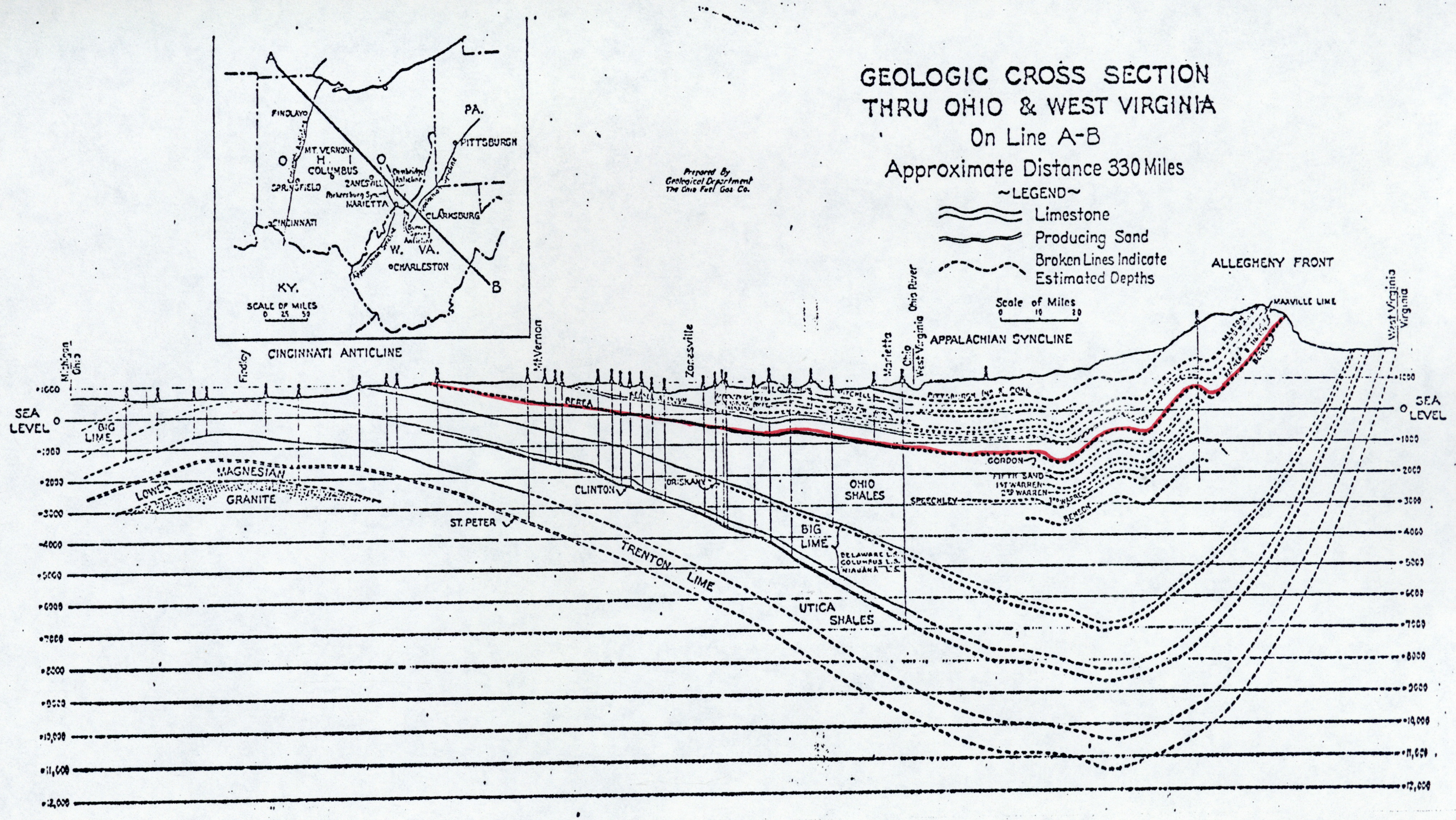
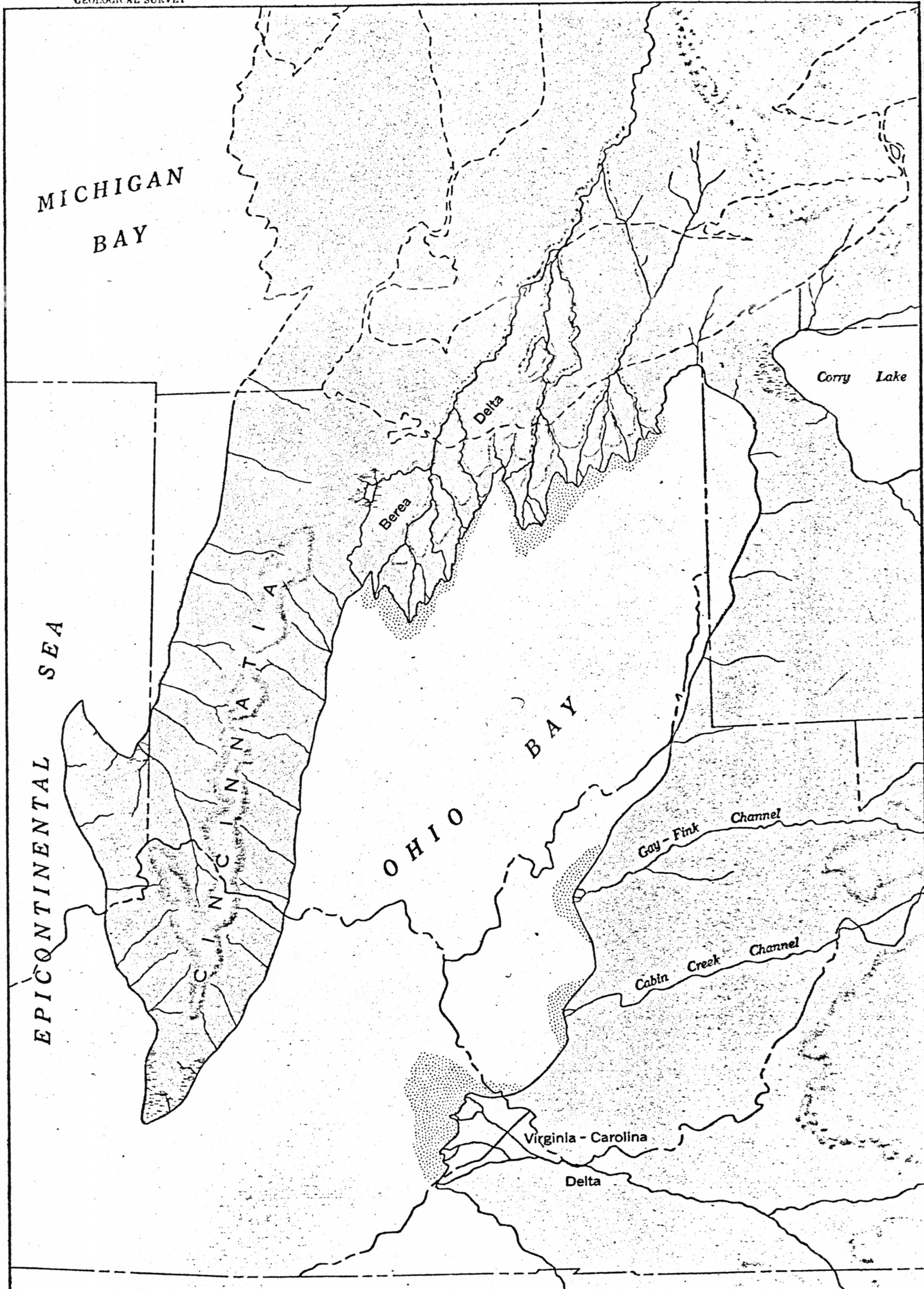

GEOLOGIC CROSS SECTION
THRU OHIO & WEST VIRGINIA
On Line A-B
Approximate Distance 330 Miles
~LEGEND~
Limestone
Producing Sand
Broken Lines Indicate
Estimated Depths
Scale of Miles
0 10 20
Prepared By
Geological Department
The Ohio Fuel Gas Co.
PA.
PITTSBURGH
FINDLAY
MT. VERNON
COLUMBUS
SPRINGFIELD
ZANESVILLE
MARIETTA
CLARKSBURG
CINCINNATI
W. VA.
CHARLESTON
KY.
SCALE OF MILES
0 25 50
A
B
CINCINNATI ANTICLINE
APPALACHIAN SYNCLINE
ALLEGHENY FRONT
MAXVILLE LIME
Michigan
Ohio
Findlay
Mt. Vernon
Zanesville
Marietta
Ohio
West Virginia
Ohio River
West Virginia
Virginia
SEA LEVEL
BIG LIME
MAGNESIAN
LOWER
GRANITE
BEREA
CLINTON
ORISKANY
ST. PETER
TRENTON LIME
OHIO SHALES
BIG LIME
DELAWARE L.S.
COLUMBUS L.S.
NIAGARA L.S.
UTICA SHALES
GORDON
FIFTH SAND
1ST WARREN
2ND WARREN
SPEECHLEY
BENSON

Figure 6.

SEDIMENTATION AND PALEOGEOGRAPHY

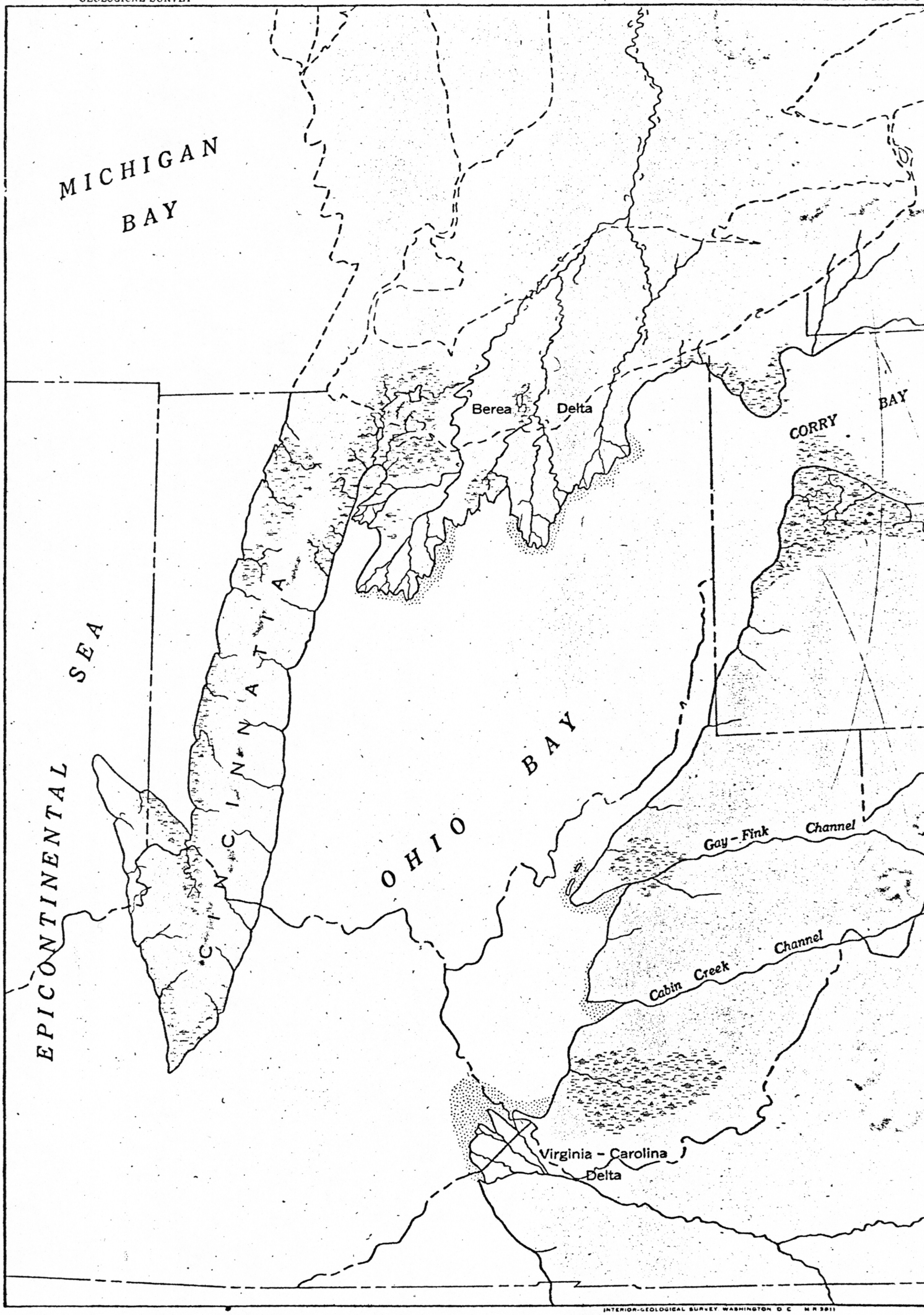
During the mid Paleozoic era, the midwest was covered by a shallow epicontinental sea. In Berea time, the sea portion covering much of Ohio was a bay named Ohio Bay by Pepper et al. (1954). It formed the Ohio Basin, bounded on the west by a long peninsula called Cincinnatia, and to the east by the Appalachian Highlands. Pepper et al., recognized three major rivers contributing sediment to the Bay, the Ontario, the Gay-Fink and the Cabin Creek. The series of paleogeographic maps illustrate the area and the changes occurring through Berea time (Figures 7, 8, 9 and 10).

The bulk of Berea Sediments were derived from a northern source. The Ontario River carried sand and silt into Ohio Bay forming the great "bird's foot" Berea Delta (analagous to the present Mississippi Delta). However, the Berea Sand in the study area was derived from an eastern source, smaller than the great Ontario River - the Gay-Fink Channel (Petter et al., 1954). The Gay-Fink spilled fine sediments into Ohio Bay where marine currents carried them northward. Pepper discovered that the boundary between the eastern source Berea and the northern source Berea sediments coincides very closely with the boundary of Pennsylvania Grade (eastern source) and Corning Grade (northern source) oil production in the Berea. Oil "grade" refers to the specific gravity and characteristic constituent hydrocarbons of crude oil.



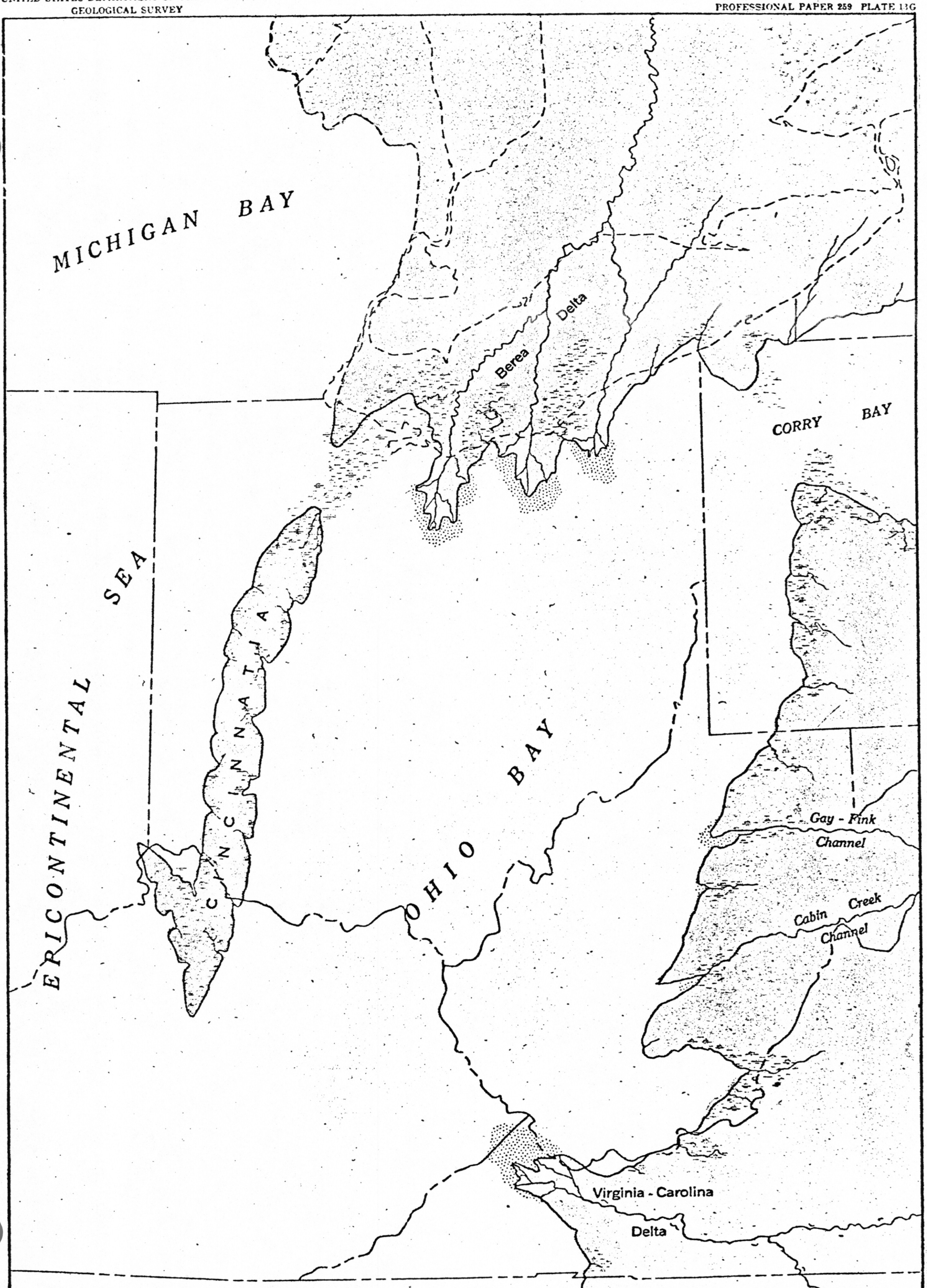
PALEOGEOGRAPHIC MAP OF EARLY BEREA TIME

Fig 7
From Pepper et al., 1954



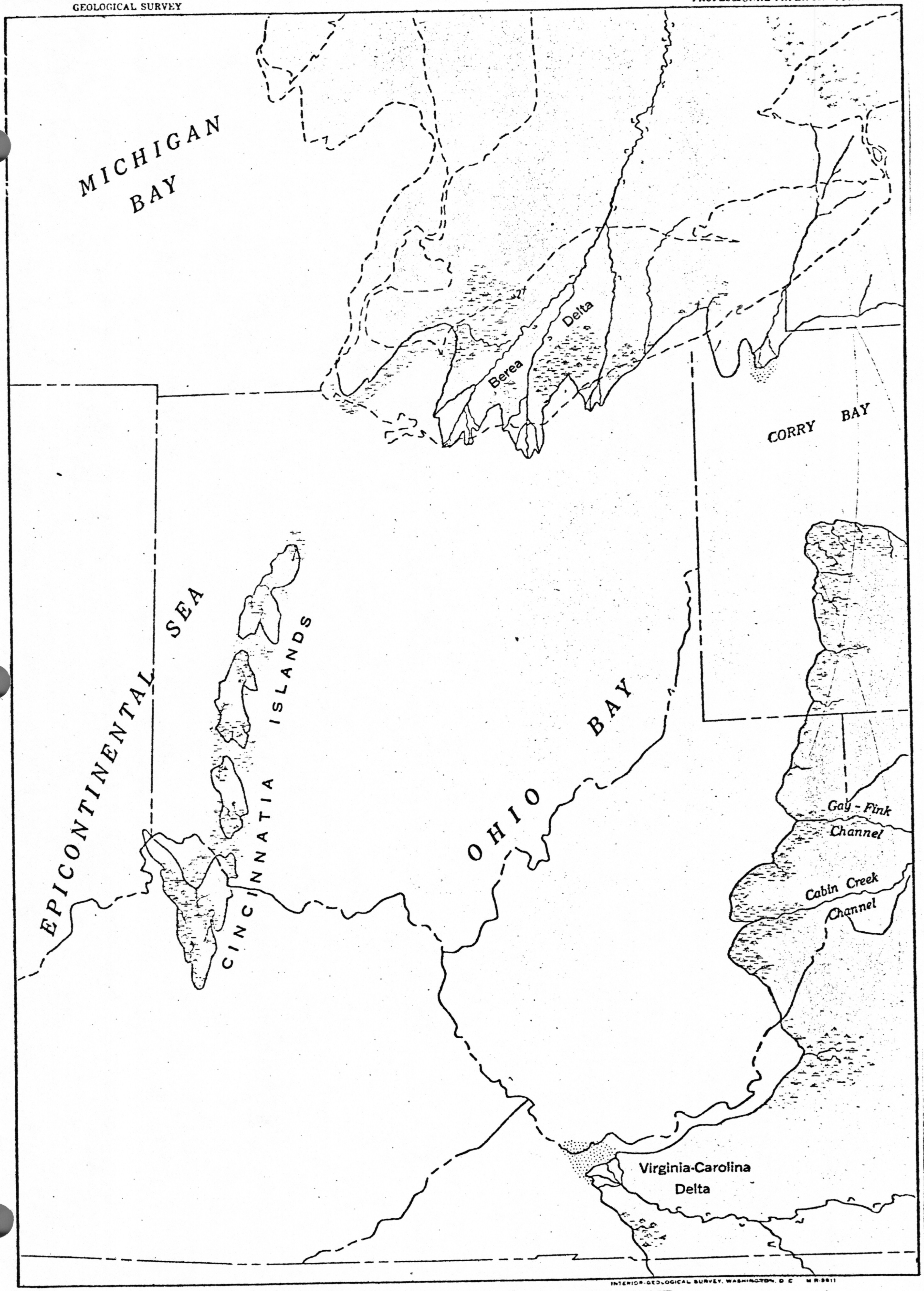
PALEOGEOGRAPHIC MAP OF MIDDLE BEREA TIME

Fig 8
From Pepper et al., 1954



PALEOGEOGRAPHIC MAP OF LATE BEREA TIME

Fig 9
From Pepper et al., 1954



PALEOGEOGRAPHIC MAP OF LATEST BEREA TIME

Fig 10

From Pepper et al., 1954

The northern source for Berea sediment was the Acadian highlands in eastern Canada. The Berea of the study area may well have been derived from Tuscarora or Oriskany Sands to the east.

The paleogeography of Ohio Bay and its fluctuations from Bedford to the end of Berea time, records transgression, regression, subsidence and great sedimentation. The large amount of sand and silt being brought into Ohio Bay caused a slow subsidence to the area. The Bay was being filled faster than it was sinking, causing an apparent regressive sequence. The region experienced this regression during early Bedford time, followed by a gradual transgression from late Bedford time through the close of Berea time. If not for this gradual rise in sea level, Ohio Bay would have quickly become dry land. This great bay of Bedford and Berea time began and ended in a state of submergence; but not before many land forms had been created and partly destroyed leaving their mark in the rock record (Pepper et al., 1954).

In middle Berea time, the epicontinental sea over North America was enlarging. Only the Berea delta was advancing as the islands of Cincinnatia and the rest of the shoreline were being inundated. Sedimentation was vigorous but subsidence was moderate, so Ohio Bay probably never exceeded 100 feet of depth (Pepper et al., 1954). The wind-wave action produced widespread oscillation ripple marks in the shallow areas. The water depth in the study area was probably deeper than most of the bay accounting for the fineness of the sediments found there today.

The end of Berea time was a period of decreased sedimentation, continued subsidence and flooding. The eastern shoreline was moved still further east by the transgressing sea. The extensive upper Berea sheet sand was deposited during this time. Within the enlargening and deepening bay, marine currents reworked the existing sediments producing the massive siltstone and fine sandstone found in the southeastern part of Ohio.

This transgression continued and by Sunbury time, the sea had covered all of Ohio and parts of Pennsylvania, West Virginia and Kentucky. Sedimentation was slight. The climate was mild and marine organisms fluorished. The result was a thick black mud covering the Berea Sediments forming what we now know as the Sunbury Shale.

GEOLOGIC CONDITIONS AFFECTING ACCUMULATION OF GAS AND OIL

It is well known that oil and natural gas migrate from a source rock until suitable conditions to accumulate is encountered, or where a barrier is reached. Such a situation constitutes a "trap". Three primary characteristics of the host rock affecting accumulations are: 1) porosity, 2) saturation, and 3) structure (Griswold, 1908).

Oil and gas bearing strata are usually sandstone, limestone or dolomite, or occasionally shale. The porosity, vital to migration and accumulation, varies within a stratum with degree of cementation, tightness of grain arrangement, grain size uniformity and roundness, and the matrix of the grains. The Berea sand of the study area, as stated earlier in this report, is a very fine sandstone or siltstone with lenses of medium grained porous sand -- ideal for oil and gas accumulation.

The saturation and structure of a formation is as vital to accumulation as well as migration. In saturated porous strata, oil and gas will be buoyed upward due to their specific gravities being less than water. Quite often, this water is saline. In unsaturated strata, oil will tend to seep downward under the force of gravity, providing it can overcome friction and capillary attraction. Structure plays an important role in accumulation. Within saturated strata, the oil and gas will occupy the crests of anticlines, tops of domes or other structural highs (see Figure 11).

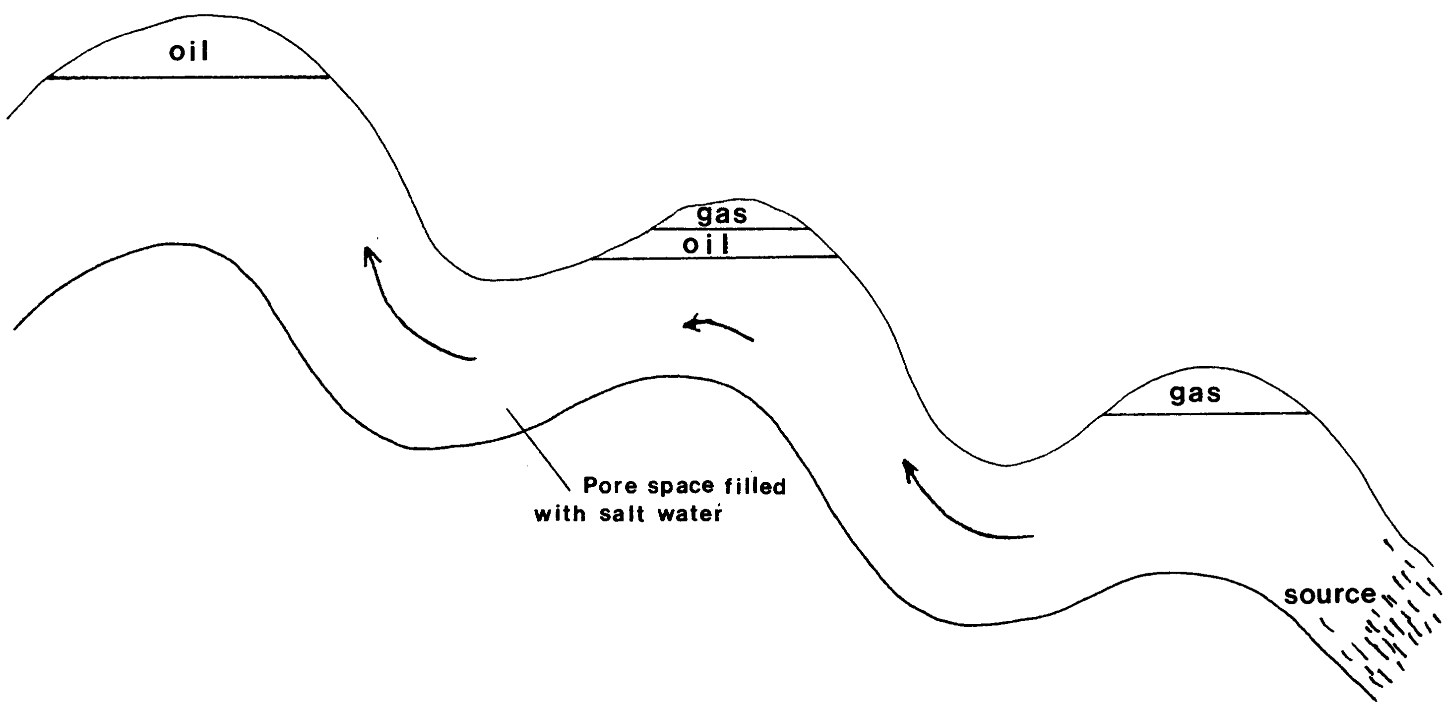


Fig.11 Diagram of oil and gas migration and accumulation in a completely saturated formation.

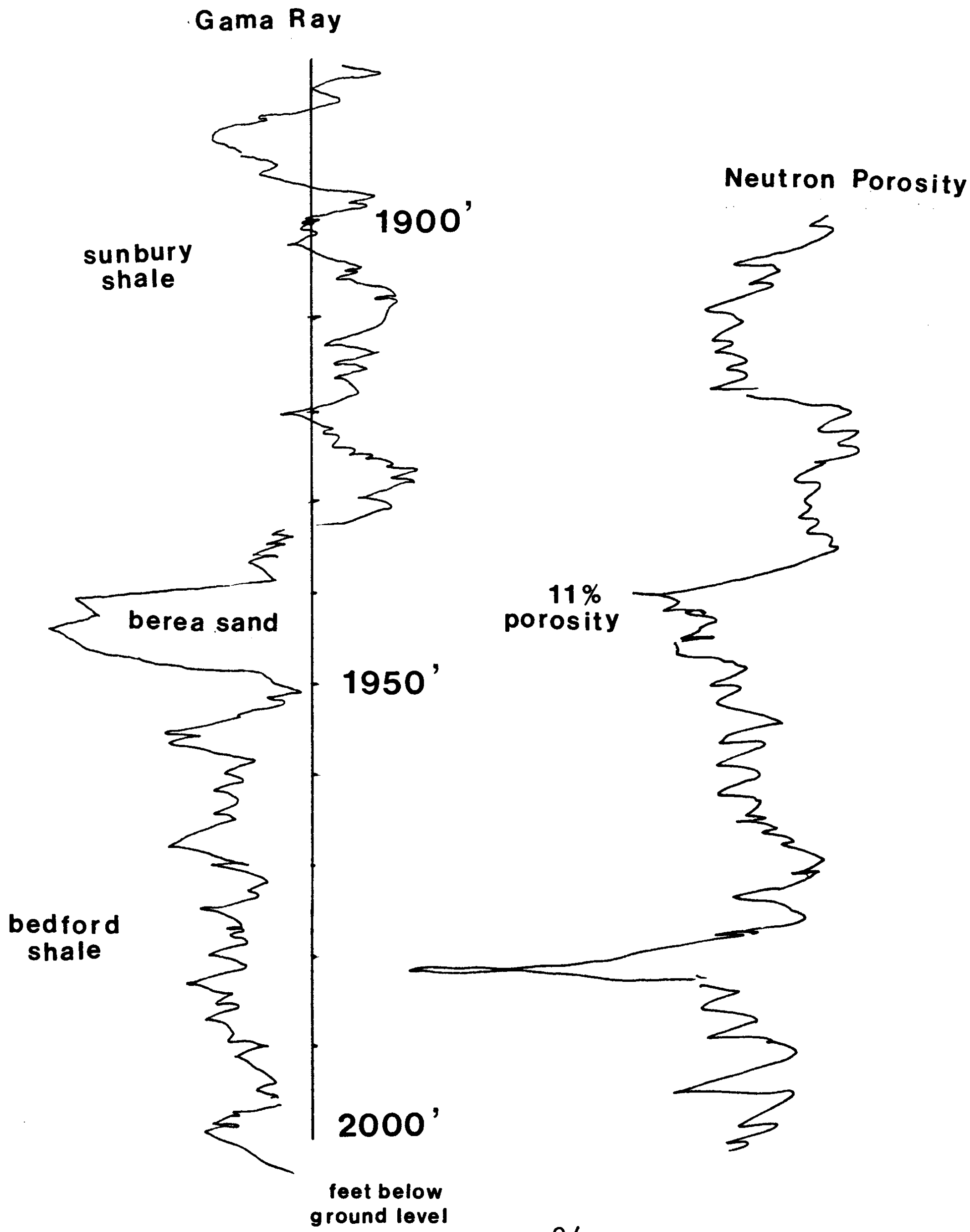
OIL AND GAS IN THE BEREA

The Berea Sand in the study area has been proven to be a good reservoir rock for oil and gas. The author has collected the following information about the conditions in the Berea in the study area. The porosity of the pay zones is reported by Manger (1963) to be as follows: minimum porosity, 4.7%; maximum porosity, 17.1%; average porosity, 11.1%; water saturation, 60%; gas and oil saturation, 40%. This is an acceptable level and agrees closely with the values the author found with the neutron/porosity logs (see Figure 12).

The logs used in this report illustrated this basic pattern: the Sunbury Shale section above the Berea exhibiting high radioactivity (gamma ray), density and low porosity (neutron curve); the Berea "kick" showing reduced gamma ray, density and increased porosity, followed by the underlying Bedford shale exhibiting similar readings to the Sunbury except lower radioactivity. Occasionally, the Berea showed a short (less than one foot) break in the gamma ray, suggesting presence of a shale lense.

The saturation has been found to be practically complete. Driller's logs report the connate water to be very saline. Though the saturation is complete, some drillers report very little or no water in formation. This is probably due to extreme "tightness" of the finer Berea sediments causing a low permeability. The water is trapped in the

Fig. 12 Sample Radioactivity Well Log - showing a typical Berea Sand signature.



pore space and cannot flow. Griswold reports the Berea as saturated to an elevation 270 to 280 feet below sea level. He goes on to state, "this is higher than any portion of the sand" (in the area). Furthermore, "under these conditions, the oil should accumulate just below the gas on the crest of the anticlinal ridges and upon terraces at the top of steep breaks."

The structure in the study area is far from complicated compared to other oil producing areas. It is actually rather monotonous, showing little change over miles and miles. The strata dips southeasterly a rate of about 20 feet per mile. This is illustrated by the structure-contour map (Plate II). This slope, though apparently uniform, is riddled with minor wrinkles which form anticlines and synclines. One dome-like feature can be seen in Malaga Township. It is unfortunate that the lack of sufficient well control prohibits a structure contour map on a smaller scale. However, insignificant these structures are on a regional scale, they are extremely influential in the accumulation of oil and gas.

The isopach map (Plate I) of this study follows roughly with the map by Pepper et al. A general thinning to the east, thickening to the northwest. The thickest Berea lies in the central portion of Belmont County where is exceeds twenty-five feet, the average thickness being ten to fifteen feet. The thickness does not seem to have much affect upon the presence of oil or gas beyond a minimum of five feet.

The structure map shows few major structures save a small dome-like feature in the northwest quarter of Malaga Township, Monroe County. The map does illustrate very well the monotonous slight southeasterly dip of the Berea. The undulations in the structure contour lines show the slight variances in dip forming "noses" in which oil and gas has been found. The most notable is an old pool in the southwest quarter of Wayne Township, Belmont County, called Malaga-Brushy Green-Harper Pools.

Other old pools in the Berea which relate to structure is the Barnesville pool, in west central Warren Township, Belmont County. This pool shows oil and gas accumulation along a steep slope downdip from a region of low dip, extending southwest-northeast parallel to strike. Another large Berea and Keener pool is located in sections 17, 18, 19, 23 and 24 of Center Township, Monroe County.

As the Berea is a reservoir formation for oil and gas, there must be a source rock from which the Bitumen may migrate. Since it may move up or down, we can look at either the Bedford or Sunbury shales as source rocks for Berea oil and gas. And indeed they may be both contributors, but the Sunbury seems to be the more likely.

The Sunbury shale is a black bituminous shale, about twenty-five feet thick on average. From the gamma ray logs, the Sunbury shows a higher natural radioactivity than the Bedford. This suggests a greater concentration of organic materials which contain the radioactivity. These organics will transform into kerogen and may then migrate. This transformation tends to create pressure within the source rock inducing the bitumen to move to an area of lower pressure, e.g. the Berea sand. This expansion may well have been the driving mechanism in the migration of oil and gas into the Berea. Fracturing and jointing in the rock provides avenues for the oil and gas to move through the shale into the somewhat permeable Berea. This migration probably took place over the course of at least one million years. The source rock for the Berea oil is purely speculative and would be an interesting area for further study.

CONCLUSIONS

The existing oil and gas pools in the study area are structural and stratigraphic traps. They are primarily anticlinal structures, or terraces. The saturation of the formation brought the oil and gas to the top of the sand and the structural highs allowed it to rise a little higher until the shale above trapped it.

The discovery of new pools within the Berea seems unlikely, but further exploration should not be discouraged. Ohio independent oil companies drill a few successful wells to the Berea each year. Also, there are other horizons which have proven to be successful producers such as the Gordon, Fourth, Fifth, Keener, and Big Injun sands (see Figure 5). Fortunately, a relation between structural undulations in the Berea can be established with these other horizons. A key to future development of new pools or extensions of existing pools may very well be a closer look at Berea structure maps. One outfit has drilled successfully to the Gordon following a structural high exploited first as a Berea field in Wayne Township, Belmont County.

Condit (1915) noted close, but not exact, coincidence of undulations found in the Pittsburgh coal to those in the Berea. He states that with appropriate well control, corrections could be made to more precisely map the Berea with the aid of Pittsburgh coal maps in some areas. With further study, perhaps a similar study could be made to infer structures and potential traps in stratigraphically lower sands.

With no end in sight to the world's demand for natural gas and oil, exploration of new potential areas -- offshore and deep inland will be exploited. There will be a time, however, when exploring these far reaches of the earth will no longer be profitable. Then, equipped with new technology, producers will come back to areas like southeast Ohio to re-work the old Berea fields. Some day science will develop better recovery techniques to allow commercial oil production to continue in southeastern Ohio.

APPENDIX A

Data from Radioactivity Logs Used in Preparing Isopach Map of Berea

Permit #	County	Township	Section	Thickness of Berea (feet)	Depth of Berea Below Mean Sea Level (feet)
281	Belmont	Goshen	3	20	714
279		Goshen	28	20	638
277		Mead	21	7	657
298		Smith	22	22	N/A
?		Smith	8	15	835
334		Somerset	1	12	722
396		Somerset	2	N/A	N/A
374		Somerset	8	8	745
350		Somerset	12	15	631
275		Somerset	13	7	733
319		Somerset	13	14	744
357		Somerset	13	10	714
322		Somerset	26	9	660
360		Somerset	32	9	649
375		Somerset	14	10	N/A
330		Warren	10	12	600
432		Wayne	16	20	N/A
352		Wayne	26	18	735
370		Wayne	26	13	754
431		Wayne	20	16	N/A
293		Wayne	14	11	821

Permit #	County	Township	Section	Thickness of Berea (feet)	Depth of Berea Below Mean Sea Level (feet)
433	Belmont	Wayne	25	20	N/A
371		Wayne	31	12	772
239		Wayne	31	12	N/A
2006	Monroe	Malaga	5	7	802
2059		Malaga	5	9	840
1941		Malaga	6	9	876
1995		Malaga	9	5	805
1984		Malaga	10	8	808
2246		Malaga	10	8	741
2247		Malaga	10	13	791
1895		Malaga	11	7	775
2131		Malaga	16	9	745
2089		Malaga	17	8	732
2120		Malaga	18	9	766
1936		Malaga	21	12	649
2072		Malaga	21	10	766
1959		Malaga	23	8	718
1960		Malaga	23	6	718
2205		Malaga	27	6	735
2057		Malaga	28	10	842
1336		Adams	25	12	1021
434-A		Sunsbury	N/A	17	879
2596		Center	5	12	N/A
2452		Center	8	5	N/A

Permit #	County	Township	Section	Thickness of Berea (feet)	Depth of Berea Below Mean Sea Level (feet)
2445	Monroe	Center	25	10	N/A
2049		Center	N/A	10	
2091		Seneca	6	12	622
1996		Seneca	10	8	682
2002		Seneca	22	6	622
1879		Summit	5	6	750
1980		Summit	18	11	884
2018		Summit	19	5	844
1999		Summit	20	5	791
2079		Summit	25	7	784
2080		Summit	25	8	770
2163		Summit	25	8	793
2164		Summit	25	7	778
1972		Summit	36	9	754
2000		Switzerland	17	18	490
1919		Switzerland	28	15	385
2001		Switzerland	N/A	N/A	N/A
1745		Switzerland	N/A	N/A	N/A

GEOLOGICAL SURVEY OF OHIO

OIL AND GAS WELL LOG

State ohio
County Belmont Township Puttney Quadrangle
Lot Quarter Tract Section 30 NW NE SW
Measured Feet From Line And Feet From Line Of

Land Owner City of Bellaire Well No. 1 Date Started 11-3-48
Operator Imperial-glass Corp. Well No. Date Completed 1-12-49
Elevation Bar. S. L. Total Depth 4506' Plugged Back
Formation Drilled To Producing Form. Init. Prod. Nat. dry
Shot or Acid Record Prod. A. S. or Acid
Init. Rock Press. Abandoned
Casing Record sample description by R.E.Lamborn

Formation	Top	Bottom	Remarks
Marville limest.	958	965	Ls., gray to brownish gray, dense to finely cryst.; a few sand grains
	965	970	Ss., gray, coarse grained, grain free; 20% gray ls.
	970	996	Ss., fine to coarse, grain free, lime bonded; a few frag. of ls; pyrite in lower part
Lime sand	996	1005	Ss., fine grained, grain free, with lime bond, 5% ls. frag.
	1005	1011	Ss., coarse grained, grain free 40% with greenish gray siltstone 60%
	1011	1018	Ss., coarse grained 10%, gray siltstone with trace shale 90%
	1018	1038	Sandstone, gray to white, aggregates and grain free; some lime bond
	1038	1063	Ss, white, fine to coarse, grain free.
	1063	1073	Ss., light buff, med. grained, grain free
	1073	1105	Ss., generally light buff, med. gr. aggregates and grain free
	1105	1123	Ss., gray, coarse to fine gr. in aggregates
	1123	1132	Same, much pyrite, with fragments of hard brown siderit
	1132	1152	Same, some gray black shale
	1152	1162	Ss., gray to light buff
	1162	1190	Same; trace of pyrite
Base of Ss. 1206	1190	1206	Ss., gray med to fine gr.; much brown siderite
	1206	1226	Shale, gray black, silty, micaceous
	1226	1235	Same, 50% dark gray siltstone
	1235	1242	Shale, gray black micaceous
	1242	1246	Shale, gray black to brown, 50% dark gray siltstone
	1246	1256	Sand grs. med. 40%; shale as above 60%
	1256	1265	Chert, gray 50%; shale 50%
	1265	1290	Shale, gray black 70-90%; gray siltstone 10-30%
	1290	1318	Shale, gray black; trace of siltstone
	1318	1329	Shale, gray black 50%; siltstone gray 50%
	1339	1348	Shale, gray black, 60% siltstone 40%
	1348	1369	Siltstone, gray slightly calcareous; trace of gray black shale
	1369	1388-	Siltstone, gray, 30%; shale, gray black 70%
	1388	1405	Siltstone gray 50%; shale, gray black 50%
	1405	1431	Shale, gray black
	1431	1481	Shale, gray black; 5-10% gray black siltstone
	1481	1491	Shale, gray black;50%; shale gray black 50%
	1491	1535	Shale, gray black
	1535	1562	Shale, gray black, micaceous
	1562	1578	Same, trace of siltstone
Berea sand	1578	1588	Shale, gray black, 50% gray siltstone

Sample Log # 40

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GEOLOGICAL SURVEY OF OHIO

OIL AND GAS WELL LOG

State Ohio
County Belmont Township Smith Quadrangle Clarington
Lot Quarter Tract Section 19 NW $\frac{1}{4}$ NE SW
Measured 421 Feet From S Line And 260 Feet From E Line Of Section

Land Owner T.H.Mobley(or E.A.Mobley Well No. 8* Date Started 2-12-40
Operator NaturalGas Co. of W. Va. Well No. Date Completed 2-7-41
Elevation Bar. 1174 S. L. Total Depth 7887 Plugged Back
Formation Drilled To red shale Producing Form. Berea sd., Gordon sd. Init. Prod. Nat. show of gas & oil
Shot or Acid Record Prod. A. S. or Acid dry hole
Init. Rock Press. Abandoned
Casing Record Samples by R.E.Lamborn

Formation	Top	Bottom	Remarks
Pennsylvanian	675	803	Red brown and greenish gray calcareous shales
	803	807	Red, brown and black shales; 5% coal frag wilgus?
	807	825	Red, brown and dark calc. shales
	825	841	Dark gray mic. sandstone, medium grained, small amt of gray shale
	841	845	Red and brown shale, some clay
	845	880	Bluish gray sandy, mic. shale
	880	888	Same, some coal frag
	888	895	5% coal, some ls, ss.
	895	905	Clay, bluish, a few frag of ls.
	905	934	Clay, sandy shale, and thin ss.
	934	965	Bluish gray shale, and thin ss.
	965	966	gray chalky ls and shale
	966	1014	Med to coarse gray ss.
No. 6a coal	1014	1024	30% gray shale, 70% coal
	1024	1076	Chiefly dark micaceous shale, a little ss.
No. 6 coal	1076	1084	50% coal; 50% shale and clay
	1084	1107	Bluish gray shale, a few frag of coal at base
No. 5 coal	1107	1110	15% coal, 85% gray ss. and shale
	1110	1189	Bluish gray sandy shale
	1189	1234	Gray ss., micaceous, med. gr.
	1234	1295	Dark sandy micaceous shales
	1295	1415	Ss. and sandy shales, interstratified
1413-39 Maxville J.H.C. Martens of W. Va. Sur.	1415	1521	White quartz ss., many pebble layers in upper part
	1521	1530	Dark gray shale, 10% gray ss.
	1530	1663	Light gray to light bluish gray ss., generally fine gr.
Mississippian	1663	1674	50% ss; 50% bluish gray sandy shale
	1687	1874	Bluish gray shale with varying amounts of bluish gray fine grained ss.
	1874	1886	Bluish gray sandy shale
	1886	1940	Bluish gray shale with thin fine grained ss., interstratified
	1940	2002	bluish gray shale
Berea sand	2002	2014	30% light buff ss. 70% bluish gray shale
	2014	2027	white to light gray med gr ss.
	2027	2042	10% light buff fine gr ss. 90% bluish gray shale
	2042	2286	Chiefly bluish gray shale; some thin beds of brown shale
Sandstone	2286	2299	90% dark brown shale 10% bluish gray shaly ss.
	2299	2312	60% dark bluish gray shale; 40% fine grained ss.
	2312	2343	Dark bluish gray sandy shale
	2343	2353	60% gray brown fine gr. ss; 40% dark bluish gray shale
	2353	2365	50% dark fine gr. shaly ss., 50% dark sandy shale
	2365	2395	Dark bluish gray shale
	2395	2412	10% gray fine gr. ss., 90% dark shale
	2412	2751	Dark bluish gray shale, somewhat sandy

Sample #307

GEOLOGICAL SURVEY OF OHIO

OIL AND GAS WELL LOG

\# 290

State Ohio

County Monroe Township Center Quadrangle

Lot Quarter Tract Section 6 NW NE SW

Measured Feet From Line And Feet From Line Of

Land Owner Kerr Well No. 1 Date Started

Operator South Penn Oil Co. Well No. Date Completed

Elevation Bar. S. L. Total Depth Plugged Back

Formation Drilled To Producing Form. Init. Prod. Nat.

Shot or Acid Record Prod. A. S. or Acid

Init. Rock Press. Abandoned

Casing Record Sample record by R.E.L.

Formation	Top	Bottom	Remarks
	1615	1617	Sandstone, white--10%;Shale, sandy dark--90%
	1617	1645	Sandstone, gray, part, grain free
	1645	1653	Shale and shaly sandstone
	1653	1660	Sandstone, gray--25%;Shale--75%
	1660	1676	Sandstone, white to gray, grain free, medium to fine
	1676	1700	Sandstone, buff
	1700	1705	Sandstone, chips, stained yellow brown
	1705	1712	Sandstone, buff, micaceous
	1712	1717	No sample
	1717	1767	Sandstone, white to gray to light buff
	1767	1777	Sandstone 50%; Shale--50%
	1777	1822	Shale, bluish gray, some sand shells
	1822	1845	Shale, bluish gray
	1845	1865	Shale and sand shells
	1865	1898	Shale, bluish gray
	1898	2003	Shale, bluish gray, sandy, micaceous
	2003	2026	Shale, bluish gray and sand shells
	2026	2103	Shale, bluish gray, sandy
	2103	2110	Shale, bluish gray;75% gray sand
Berea Sand	2110	2121	Sandstone, gray, very fine grained, micaceous
	2121	2129	Shale, bluish gray; 20% fine grained sand
	2129	2137	Shale, bluish gray; 10% sand shells
	2137	2154	Shale, bluish gray; 50% sand shells
	2154	2189	Shale, bluish gray
	2200	2209	Shale, bluish gray, and shaly sandstone
	2209	2224	Shale, bluish gray, and brown black
	2224	2229	Same, some calcareous and ferruginous
	2229	2238	Shale, bluish gray and brown black, sandy micaceous
	2238	2286	Shale, bluish gray and brown black, sandy, micaceous with many calcareous pieces
	2286	2305	Shale, bluish gray, sandy to coarse silty
	2305	2335	Same
	2335	2376	Shale, bluish gray, sandy
	2376	2388	Shale, bluish gray, sandy;10% sand shells
	2388	2395	Shale, bluish gray, sandy-25%;sand, gray, fine grained--75%
	2395	2405	Shale, bluish gray; 10% gray sand shells
	2405	2410	Shale, bluish gray; 70% gray, fine grained sandstone
	2410	2505	Shale, bluish gray, sandy
Probable base of Mississippian System(?)			
	2505	2525	Shale, bluish gray; 10% red brown shale
	2525	2547	Shale, bluish gray,50-75% fine grained sandstone
	2547	2600	Shale, bluish gray
	2600	2625	Shale, bluish gray, some calcareous pieces
	2625	2695	Shale, bluish gray, sandy
	2695	2710	Shale, bluish gray

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